Chances of Loss of Merchant Ships.

By W. S. Abell, Chief Ship Surveyor, Lloyd's Register of Shipping.

(Communicated by Prof. W. Burnside, F.R.S. Received August 14, 1918.)

The enormous losses of merchant ships arising from the operations of enemy submarines have caused considerable attention to be directed to the question of water-tight subdivision of such vessels. One method of obtaining increased protection is to provide additional bulkheads, which would materially prevent loss of vessel if the intactness were likely to be preserved. In view, however, of the considerable extent of torpedo damage in the longitudinal direction, it is obvious that there is an inferior limit to the spacing of the bulkheads below which the protection afforded is practically useless.

In addition to such objection, a close spacing of bulkheads materially increases the difficulties of loading and unloading, and consequently decreases the time-capacity of the vessel to transport goods.

The correct spacing to obtain the maximum efficiency of transportation must depend on a calculation of the probability of loss of one or more bulkheads, and of the consequent effect of the loss of these bulkheads on the ultimate chances of the sinkage of the vessel.

The first step to be taken is to obtain an approximate estimate of the chance of loss of bulkheads, and for that purpose it may be assumed that the intactness of water-tight subdivision will be destroyed within some radius, R, of the centre of explosion of a torpedo. The great majority of cargo steamers can only be provided with vertical tranverse bulkheads, and consequently it is only necessary here to consider the aspects of the case where R is a horizontal distance from the centre of explosion.

Case I. Spacing $> 2\mathrm{R} = (2\mathrm{R}+a)$.

If the explosion occurs at a distance, R, from the bulkhead, the intactness is destroyed, and consequently within a space $(2\mathrm{R}+a)$, bounded by a bulkhead at each end, the horizontal length wherein the vessel may be hit without damaging a bulkhead is a, and the length where the contrary effect is produced is 2R.

The "odds on" for loss of a bulkhead are therefore $2\mathrm{R}/a$.

The properties of the curve $2\mathrm{R}/a$ are simple, and when $2\mathrm{R}+a$ is great compared to 2R the odds on loss are small. As the value of $2\mathrm{R}+a$ decreases, the "odds on" rapidly increase until, where the spacing is within about 15 per cent. greater than 2R, the rate of increase of odds is extremely rapid. When the spacing is very nearly 2R the "odds on" for loss of one

bulkhead are, of course, very nearly infinite. It is therefore important that the spacing of bulkheads shall be greater than $1{\cdot}15 \times 2R$, in order that the probability of loss shall not be largely and unduly increased.

Case II. Spacing $< 2R = (2R - a)$.

In this case one bulkhead will be damaged in every instance, and it is now necessary to calculate the chances that two bulkheads will be destroyed by one explosion.

Considering the space $(2R - a)$ bounded by a bulkhead at each end, the length wherein two bulkheads will be damaged must be the space which is at, or less than, R feet from either bulkhead. The length of this danger region is obviously a, and the remaining length is $(2R - 2a)$; consequently, for the loss of two bulkheads the "odds on" are $a/2R - 2a$.

The variation of this relation is generally similar to the previous one, except that when the spacing is $= 2R$, or $a = 0$, the "odds on" loss for two bulkheads is zero. On the other hand, when a approaches R the odds on loss approach infinity; in fact, as in the previous case, it is desirable to avoid spacing of bulkheads lying between $1{\cdot}15$ R and R in order to confine the probability of loss to reasonable limits.

Case III. Spacing $< R = (R - a)$.

It is obvious, apart from the resistance offered by a bulkhead to distortion under the effects of an explosion, that whenever the spacing is less than R, two bulkheads are rendered ineffective. Case III resolves itself into a calculation to determine the probability of damaging three bulkheads. By similar reasoning to that previously adopted, it will be seen that within a region, a, on each side of a bulkhead, it is possible to destroy three bulkheads. Consequently, since the remaining space is $(R - 3a)$, the "odds on" for loss of three bulkheads are $2a/R - 3a$.

The form of this fraction follows the same general nature as the previous case, and is subject to the same approximate limitation that spacings between $1{\cdot}15\,(2R/3)$ and $2R/3$ should be avoided.

Application of Results to Actual Vessels.

As the conditions of flotability vary considerably with the type of vessel, which again is related to the service for which a vessel is designed, it is preferable to confine our attention to ordinary cargo steamers. Such vessels are usually provided with a forecastle, bridge, and poop, and in the discussion which follows, it is assumed that the freeboard is the minimum permitted under the Load Line Acts.

The spacing of bulkheads, in an actual ship of given dimensions, draught,

and type, is dependent on the nature of cargo carried and on the permeability, *i.e.*, the amount of water which will fill the spaces unoccupied by cargo. It is extremely probable that the conditions obtaining at the time of damage will differ radically from the assumptions made, and there will be in general an increased risk of loss arising from such difference.

The "floodable length," or the length which may be flooded without loss of ship under assumed conditions of loading and of permeability, bears a fairly constant relation to length of vessel, since the type is fixed. The floodable length necessarily varies throughout the length, being greater at the ends and amidships than it is in the forward and after holds; the approximate minimum values of the floodable length have therefore been taken, since these values will give the maximum probability of loss.

In vessels of the ordinary cargo type the permeability, coefficient of fineness of form, and ratio of sheer of the bulkhead deck to length are practically constant for varying length of ship. The minimum freeboard permitted by the Load Line regulations varies so that the ratio of freeboard to draught actually increases with length of vessel.

The minimum floodable lengths are obtained from the Board of Trade standard curves, which give the percentage of length which can be flooded in terms of coefficient of fineness of form, ratio of freeboard to draught, and ratio of sheer of bulkhead deck to draught. These minimum floodable lengths when plotted on a base of length of ship lie approximately on a straight line.

When the bulkheads throughout a ship are so spaced that any one compartment can be flooded and the ship remain afloat, the flotability is defined as a "one-compartment" standard. When the arrangements are such that any two adjacent compartments can be flooded without loss of vessel, the standard is designated "two-compartment," and a similar notation is given to higher degrees of subdivision. Such definitions necessarily imply that the bulkheads bounding the flooded space remain intact.

Since the damage inflicted by a torpedo explosion is limited in extent, it is evident that the larger the vessel the greater the floodable length and the greater the chance of remaining afloat after a hit. On the other hand, starting from a "one-compartment" standard, where the spacing of bulkheads is the floodable length, and where the loss of one bulkhead means the sinkage of the vessel, it is obvious that the chances of damage of a bulkhead, *i.e.*, the chances of loss of vessel, continuously increase as the bulkhead spacing diminishes. The risk of loss from torpedo explosion therefore increases very rapidly until a "two-compartment" standard is obtained.

With the type and freeboard assumed the "two-compartment" standard can only be obtained in two ways:—

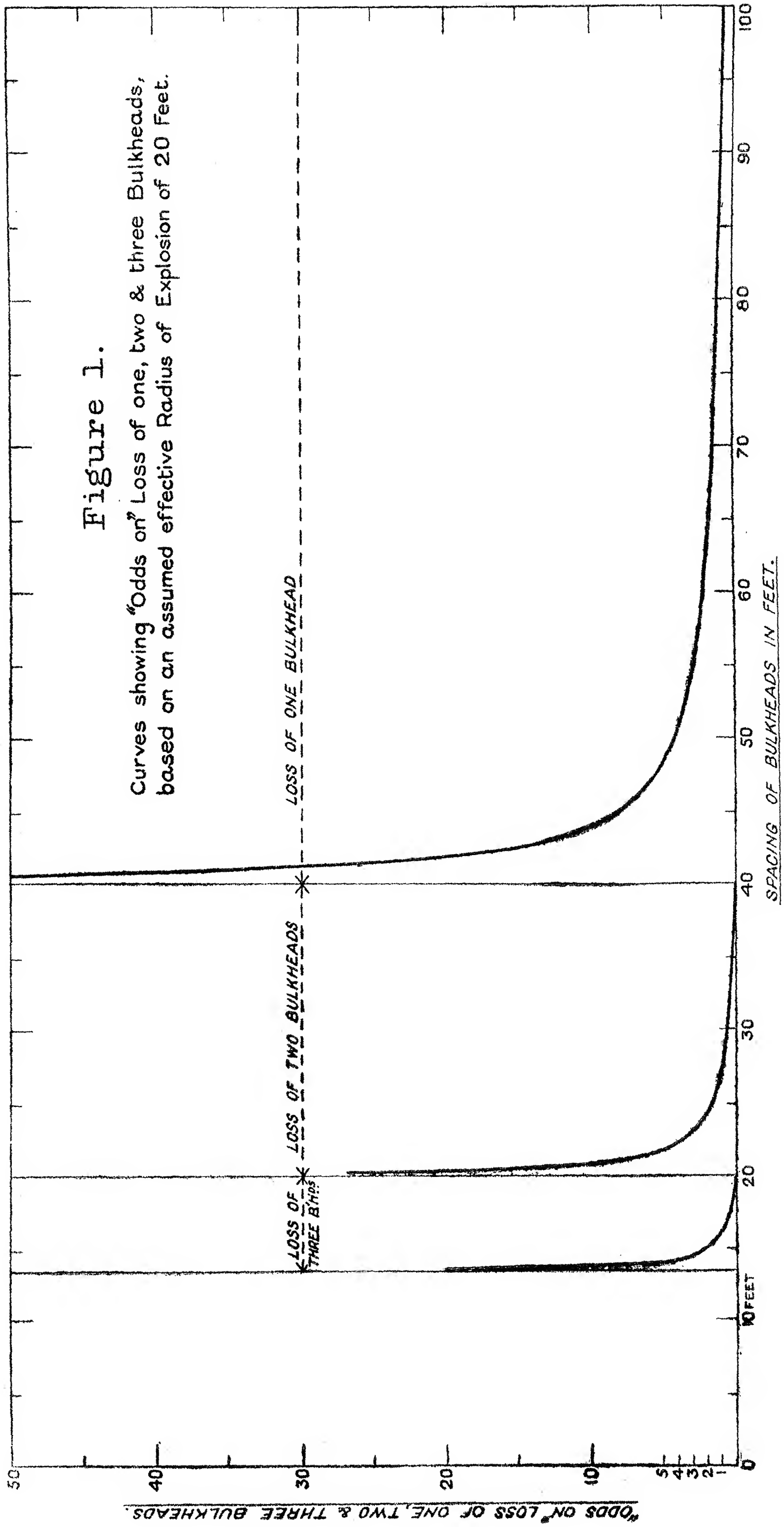


Figure 1.

Curves showing "Odds on" Loss of one, two & three Bulkheads, based on an assumed effective Radius of Explosion of 20 Feet.

1. By building ships of such size that the floodable length is somewhat in excess of twice the diameter of the explosion circle; or

2. By increasing the freeboard, and thereby deliberately sacrificing the carrying power of the vessel, in order to provide increased protection.

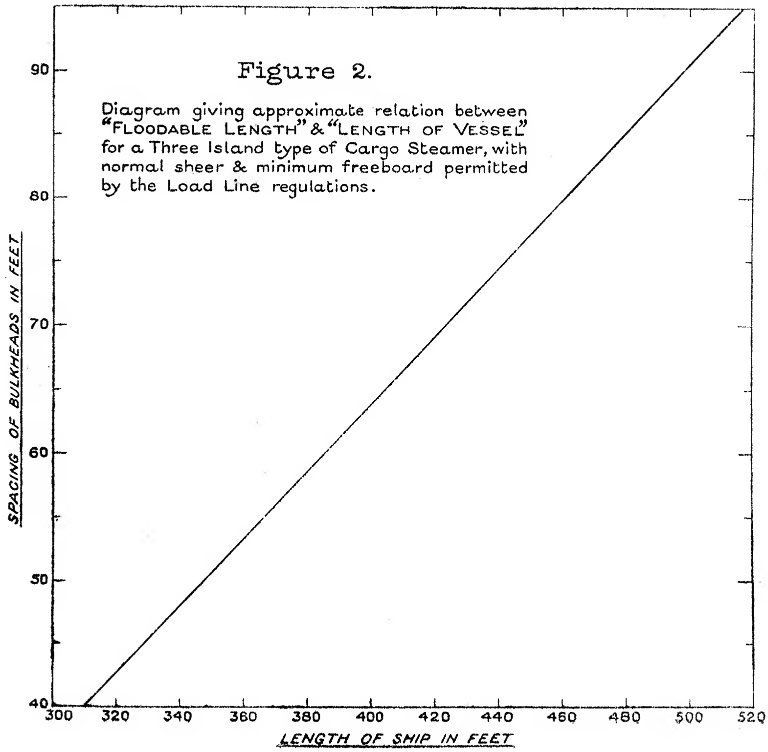
The further discussion of the subject will probably be more intelligible if figures be taken for the various quantities involved.

Numerical Results.

The value of R, the radius of damage from a torpedo explosion, has to be assumed, and for the purposes of the argument it is desirable to keep the estimate on the large side. Experience indicates that R = 20 feet would be a good approximation.

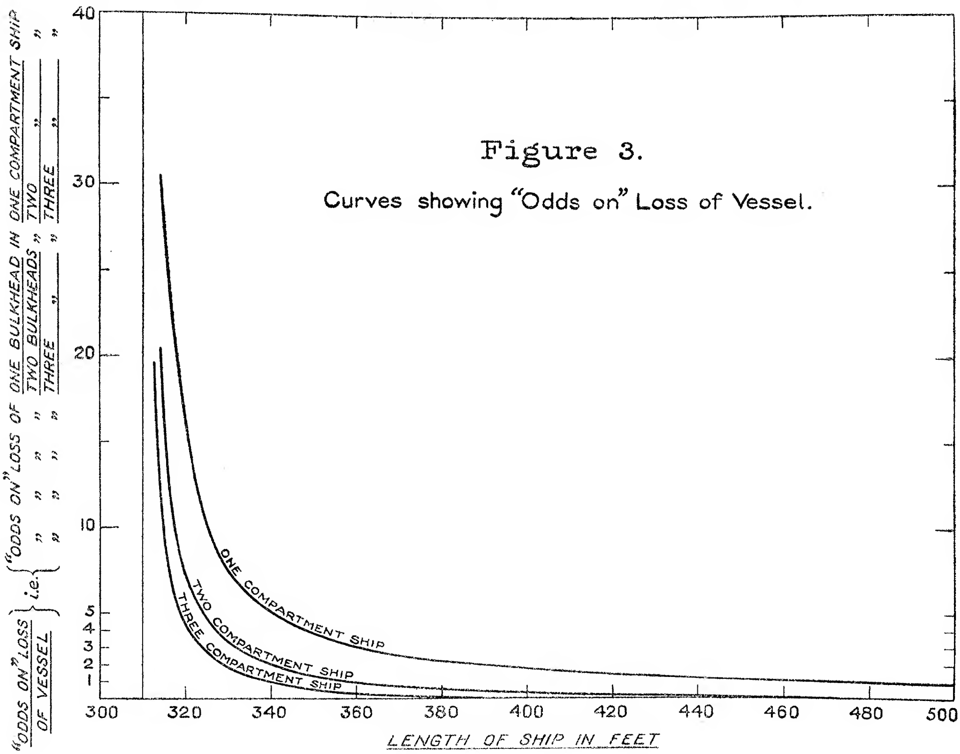
Fig. 1 illustrates the "odds on" for loss of one, two and three bulkheads, expressed as ordinates on a base of bulkhead spacing. This diagram shows the desirability of avoiding spacings which lie between 40 and 47 feet, 20 and $23\frac{1}{2}$ feet, and $13\frac{1}{3}$ and 15 feet for the one, two, and three bulkhead losses respectively.

Fig. 2 is a scale diagram giving the approximate relation between



"floodable length" and "length of vessel" for a cargo steamer, with forecastle, bridge, and poop of normal extent, with the minimum freeboard permitted by the Load Line regulations.

Fig. 3 is obtained by combining the results of figs. 1 and 2, and gives as ordinates the "odds on" for loss of vessel, *i.e.*, the "odds on" for loss of one bulkhead for a "one-compartment" ship, two bulkheads for a "two-compartment" standard, and three bulkheads for a "three-compartment" vessel.



The following deductions may be drawn:—

1. Decrease of size of a large vessel only slightly increases chances of loss. In a "one-compartment" ship, where the bulkhead spacing is equal to the floodable length, the "odds on" for loss of vessel are 1 to 1 for a vessel 460 feet in length, and about 2 to 1 for a length of about 385 feet. With a "two-compartment" standard, the "odds on" for loss are practically "nil" at about 460 feet, although owing to the limitation of spacing already mentioned, the length of ship should preferably be nearer 500 feet.

For vessels of length of about 340 feet and below, the risk of loss of ship is relatively high, and with very little diminution in length the "odds on" for loss increase very rapidly. From the diagram, ignoring the resistance

afforded by a bulkhead to distortion under torpedo explosion, it is extremely doubtful whether any subdivision by transverse water-tight bulkheads, however great, is likely to be effective when the length of the vessel is about 320 feet or less than that amount.

3. As illustrating the increase of safety arising with the larger vessel it may be observed that:—

(*a*) A vessel of 460 feet length with the "one-compartment" standard is as safe as one of 360 feet length subdivided on the "two-compartment" system.

(*b*) A vessel of 500 feet length with bulkhead spacing equal to floodable length is as safe as one of 345 feet length with bulkheads arranged for a "three-compartment" standard.

4. The effect of the adoption of intermediate bulkheads in a one-compartment ship (in order to comply with, say, the two-compartment standard), varies considerably with the length of vessel. Whereas, in the 500-feet vessel the two-compartment standard is practically immune as compared with the one-compartment, yet at 340-feet length the three-compartment vessel is only twice as safe as the two-compartment system, and the latter is only $2\frac{1}{2}$ times as safe as with the one-compartment standard. In addition, spacing of intermediate bulkheads should avoid more particularly the dangerous limits such as 20–$23\frac{1}{2}$ feet already mentioned.

General Remarks.

The discussion of this particular phase of the problem suggests that, with reasonable assumptions as to the value of R, it should be possible to arrive at some conclusion respecting the amount of subdivision to be provided to meet conditions attached to ordinary marine risks.

Further, that if any means could be devised to limit the longitudinal extent of damage arising from torpedo explosion, a great increase in safety would result. For example, if the value of R could be confined to, say 16 feet, as compared with 20 feet, the "odds on" for loss of one-compartment vessels would be reduced by 33 per cent. for a ship of 460 feet length, by 40 per cent. for 400 feet length, and by 60 per cent. when the length is 340 feet.